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Final Project Report

Study of the Frog Pond area hydrology and water quality modifications introduced by the C-111 Project detention pond implementation

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Executive Summary

The extensive boundary of Miami-Dade County (FL) with the Everglades National Park (ENP) is subject to the most expensive and ambitious restoration project in history. One of the elements that can help to fine-tune the balance between the many, sometimes conflicting, land uses in the area (agriculture, urban development and restoration) is an enhanced understanding through research and education of how the regional water management system (canals and structures) interact with the extremely permeable aquifer in the area. The objective of the present study was to study the interaction between the regional water management system and local hydrological conditions at the small-watershed/farm scale. This was achieved by establishing the effect of canal elevation and rainfall on local ground water flow and quality, and by calibrating and testing a field/farm watershed scale computer model as a potential management tool for the area

The Frog Pond, a small (23 km^2) agricultural watershed adjacent to ENP, was selected for this study. Several C-111 Project actions, under the IOP (Interim Operation Plan) for Protection of the Cape Sable Seaside Sparrow, are currently being implemented in the area (modified L-31W canal management, detention pond). A network of 16 wells with automatic logging of groundwater heads, 4 surface stage recorders (at the canals/ditches surrounding the area), 2 rain gauges, 1 automatic weather station for ET estimation and soil moisture monitoring, and a bi-weekly water quality sampling program (with over 25 chemical elements analyzed) was established by the University of Florida in March'02. A GIS system comprising different hydrological, land use and vegetation layers was developed to support this research. The resulting hydrological and water quality information has been standardized and can now be accessed remotely from a custom-designed SQL database web server (UF-HydroBase, http://carpena.ifas.ufl.edu) containing powerful reporting and plotting capabilities. This tool allows for analysis and sharing of data among researchers, managers.

The experimental results show that in a managed hydrological area like the Frog Pond, the regional water management system (canal stages) is the main factor explaining the mean seasonal groundwater profiles, rather than precipitation. However, precipitation is important to explain instantaneous or localized groundwater responses that in some cases can be directly associated with the risk of flooding. The mean annual water table elevations (WTE) across an east to west transect presents a smooth down gradient towards the L-31W canal in the west. This seems in contradiction with the nearby mean canal elevations, where because of the C-111 Project operating under the Interim Operational Plan (IOP), the L-31W maintains the highest surface water elevation at all times. In contrast, the water table depth (WTD, distance from the soil surface) varies dramatically along this transect due to the local changes in surface elevation (around 30 cm or 1 ft). This illustrates the importance of micro-topography in the extremely flat lands of South Florida. This issue is all the more important the shallower the groundwater becomes. In our conditions, a 1 ft. difference might compromise the value of the land for its intended use (agriculture, landscaping, development, traffic, restoration etc.). Currently there is no topographical data generally available in South Florida close to this resolution.

The aquifer's specific yield (S_y) was estimated by a simplified method using the high-resolution (15 min readings) water level data. The procedure led to very consistent results for the five inner wells (3 – 7) of the well transect, with a value of S_y = 0.115. This indicates that if the water table is within 2 feet of the surface and the net flow at the point is zero (lateral and vertical), 2.54 cm (1 in) of rainfall might result in a water table raise of about 22.4

cm (8.8 in). This value is in agreement with other studies in the same area but larger that the general value commonly used in the area of 7.6 cm (3 in) rise. This corroborates the marked vertical heterogeneity existing in the Biscayne Aquifer. A practical application of this finding is the fact that when the water table is already close to the surface, the risk of flooding with a new storm can be actually up to 3 times greater if calculated with the new value instead of the general value.

Complete flooding (water standing on soil surface) was experienced in 40% of the wells in the transect, with as much as 0.23 m (9 in) of ponding in one instance. All the wells had water within 0.15 m (6 in) of the surface at least at one time during the one-year period (03/28/02-/02/28/03).

Computer simulation with MODFLOW (USGS) based on the experimental results show the profound effect that the permanently closed gate at structure S-175 in L-31W (associated with the IOP modifications) has on the general groundwater flow in the southern portion of the Frog Pond. The sharp gradient of around 1 m (3 ft) between head and tail waters of the structure shifts the general west to east groundwater flow to turn around the structure with increasing speeds, and eventually west towards the ENP once south of the structure. Based on the simulation the flow perturbation reaches around 1.6-3.2 km (1-2 mi) around the structure. These explain the apparent contradictory relationship observed at the well transect between canals and groundwater elevations. After successful calibration of the model (predicted vs. observed heads nRMSE 6.3%) the local hydrological effects of filling the detention were evaluated. Results show that up 30% of water pumped into the detention pond is lost back to the groundwater system towards the C-111 canal through seepage.

Concentrations of total P in surface waters exceeded 10 ppb in 90% of the samples collected between 03/28/2002-03/28/2003. L-31W canal samples were consistently higher than those obtained from C-111. Concentrations of total P and Ortho-P in water samples from the monitoring wells were high during May-August (summer rainy season), and August-December (early growing season of vegetable crops). Concentrations of nitrate-nitrogen in all surface and groundwater samples were below 10 ppm (U.S. drinking water standard) except for two samples in June 2002. On a monthly basis, the higher groundwater nitrate concentrations were observed during the rainy season (May-August), with a second (lower) increase at the beginning of the winter crop season (September-November). This indicates a rapid mobilization (leaching) from the enriched topsoil when the rain falls. The second peak at the beginning of the crop season can also be attributed to the fertilizer applied to the soil (in beds or pre-planting). Ammonia in groundwater follows an inverse pattern to nitrate, i.e. the mean monthly ammonia concentrations are higher when nitrate is low. This might be largely the result of the chemical reduction to ammonia of the nitrate that was leached previously. Monthly nitrate and ammonia surface water concentrations followed a similar pattern to the one described for groundwater (i.e. inverse ammonia and nitrate patterns) but shifted (delayed) in time around 1.5 months, although surface nitrate concentrations were around an order of magnitude lower. High concentrations of copper were found in water samples from canals, ditch and wells in September 2002, possibly from applications in the agricultural areas to the east of the Frog Pond. Concentrations of trace metals in most of water samples were below detection limits or very low. However, some water samples showed relatively high concentrations of arsenic (69 ppb in Torcise ditch), cadmium (23 ppb in Torcise ditch), cobalt (31 ppb in Well 1), chromium (31 ppb in Well 1), nickel (34 ppb in Torcise ditch), lead (128 ppb in Well 2), and selenium (98 ppb in Torcise ditch).

This work will help assess the effectiveness and impacts of similar detention pond areas. The information will be made available to the institutions in charge of C-111 Project, as well as provided to the local stakeholders through the UF Extension program.

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Introduction

The complex canal system in South Florida is the basis of the regional water management. Although the canal system was designed, implemented and operated for flood protection in the first half of the 20th century, the more recent environmental concerns around the Everglades call for a re-assessment in the way the system will be managed to restore the ecosystem by enhancing water deliveries to the Everglades. The Central & Southern Florida Restudy (CSFR) was authorized by the Water Resources Development Act of 1992 to determine the effects of the existing canal system on the Everglades and neighboring sensitive areas. The C-111 Project, authorized by the 1994 General Reevaluation Report (GRR), was one of the products of the Restudy. When the Restudy was complete in 1999, it was renamed the Comprehensive Everglades Restoration Plan (CERP). The C-111 Project remains a separate project from CERP. The majority of the project has been constructed and is currently operating under the Interim Operational Plan (IOP) for Protection of the Cape Sable Seaside Sparrow (CSSS). This Interim Plan will be replaced by the Combined Structural and Operational Plan (CSOP), once the latter is complete. CSOP will analyze the effects of the Modified Waters Deliveries Plan (ModWaters), IOP and other adjacent projects on the hydrology of the Everglades. The time frame for completion is tentatively and unofficially within the next 2 to 3 years. This will also affect the water available for the C-111 Spreader Canal CERP project (located south and east of S-178).

Regional water management is an extremely complex problem. One of the most significant design criteria currently in place is the maintenance of existing levels of flood protection in the urban and agricultural communities in South Miami-Dade. In addition, water quality is at the core of the restoration effort. Surface waters entering the Everglades National Park must not exceed a maximum total phosphorous concentration, and other chemicals must be monitored as well.

One of the elements that can help to fine-tune both objectives (environmental restoration and flood protection in developed areas) is an enhanced understanding through research and education of how the canals interact with the extremely permeable aquifer in the area. Timing, aquifer response and maximum outflow rate are essential factors when opening and closing a canal gate to draw the water levels up or down for flood protection. Obtaining accurate canal/aquifer relationships requires very detailed watershed studies at a small scale. These types of studies are not readily available in this area since, for practical reasons, a larger scale (2x2 mi) is used for regional water management. One existing short term local scale study in the area (Genereux and Guardiario, 1998, 2001; Genereux and Slater, 1999) has shown the complexity of a groundwater system with extremely permeable materials and evidence of a very dynamic interaction between canals and the aquifers.

Data from intensive small watershed studies, when sufficiently expanded in time to include inter-annual variability, has the potential to be utilized to study the complex surface-groundwater interaction in the area, the underlying physical system, and to calibrate and test small-scale groundwater models (Morawietz, 2003). Computer models, when sufficiently tested under the field conditions where they will be applied, are powerful tools for evaluating natural resource management scenarios and for risk assessment (Muñoz-Carpena et al., 2002). Continuous monitoring in the area, concurrently with the operation of new C-111 Project elements such as detention ponds, provides an invaluable opportunity to assess the effect of these new areas. This in turn will lead to development of improved management plans and devising BMPs to mitigate possible impacts. In addition, the experimental dataset from such a project has the potential to become an outstanding educational tool both as a demonstration project and as a platform to produce sophisticated educational materials. This educational objective is inline with current initiatives by the Environmental Protection Agency (EPA) contained in the Watershed Initiative 2003 (Watershed Academy - EPA's Office of Wetlands, Oceans and Watersheds). This new initiative is calling for watershed partnerships between organizations or groups whose primary mission is to identify and address the causes, effects, extent, prevention, reduction and elimination of water pollution on a watershed basis. This represents an exciting opportunity to start a partnership between the University of Florida and state and local agencies to educate stakeholders in these issues.

Objectives

The main objective of this study is to investigate how the canals operated by the South Florida Water Management District (SFMWD) interact with the aquifer in this sensitive area of the Everglades, and to educate the stakeholders and public on standing hydrological issues in the district. This will help to fine-tune the balance between the many, sometimes conflicting, land uses in the area (agriculture, urban development and restoration). Specific objectives are:

- Establish the reach of varying canal elevations/rainfall and their seasonal relationship to ground water table depth.
- Assess water quality and seasonal variation by bi-weekly sampling at canals, ditches and wells.
- Calibrate and test field/farm scale computer models to aid in evaluating management scenarios that are developed based on regional scale models.
- Make results and recommendations accessible to stakeholders through the University of Florida Extension.

Materials and methods

Hydrological Monitoring Network

The study was conducted at the Frog Pond area, a small watershed of 2023 Ha (5000-acre) located at the boundary of the Everglades National Park (ENP) in Homestead (Florida). This public land is under interim management by the South Dade Soil and Water Conservation District (SDSWCD) and will revert to the South Florida Water Management District (SFWMD) on September 30, 2003. For the last 10 years, the area was subleased to a small group of growers that farmed under restricted conditions (low inputs, no flood protection).

Last summer a system of detention ponds and a 14.2 m^3/s (500 cfs) pumping station was constructed in the area. The construction of the S-332B, C and D structures in the Frog Pond was originally authorized by the 1994 General Reevaluation Report for C-111 as part of the Central & Southern Florida Restudy. These structures are currently operated under the IOP under an Emergency Order. The USACE has applied for a permit from the FL Dept. of Env. Protection. Under IOP, the aim is to maintain high L-31W water levels to increase water delivery into the ENP. This is achieved by keeping the gate at S-175 closed while pumping water from the C-111 canal into the L-31W in the north of the Frog Pond. Although the associated detention areas are primarily for storage, some treatment may occur by the nature of the areas. This system has the potential to significantly modify the flow patterns and chemical transport in the area.

In February 2002 the University of Florida's Tropical Research and Education Center (UF-TREC) hydrology team initiated the setup of an extensive monitoring network distributed across the southern portion of the Frog Pond watershed at the boundary of the ENP (Fig. 1). The first installation phase of the UF-TREC monitoring network (February 2002) consisted of a 1 mile transect with 10 fully instrumented wells for water elevation and water quality sampling, two rain gauges, soil moisture sensors and an automatic weather station. Groundwater levels were registered by auto-logging pressure transducers compensated for temperature effects and atmospheric pressure (Solinst Inc., Canada). Rainfall readings were made with auto-logging tipping-bucket rain gauges (Onset Computer Corp., USA) and evapotranspiration was estimated based on weather data (wind speed, solar radiation, relative humidity, air temperature, atmospheric pressure) measured with an automatic weather station placed at the well transect (at a point 2/3 of the total length).

In a second phase started early in 2003, 6 additional fully instrumented wells and 4 canal and drainage ditch stage recorders were added north and south of the original transect and included in the monitoring and sampling protocol (Fig.1 and Table 1 in Appendix). Surface water elevations in canals and ditches were recorded by a simple self-contained automatic recorder developed for this purpose (Schumann and Muñoz-Carpena, 2003). The loggers in the two canals were attached to custom-made steel and wood platforms (6x1 m) supported by pillars anchored in the banks and the bottom of the canal.

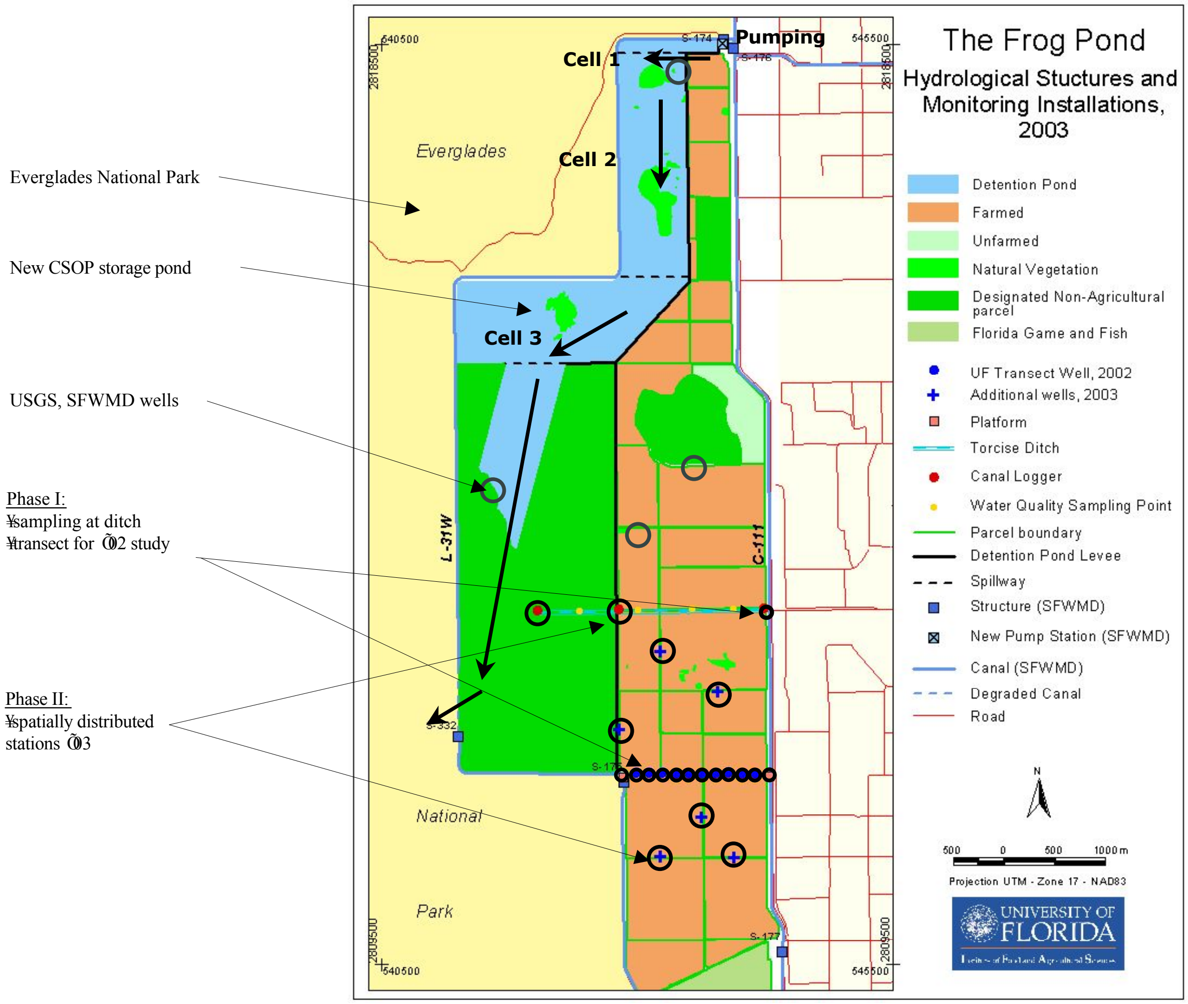

Figure 1. Monitoring network

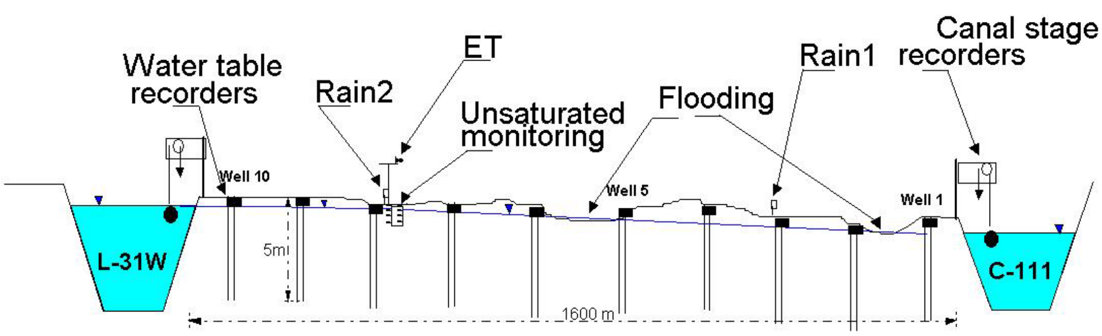

Figure 2. Well transect (Phase I- 2002)

All 23 loggers (4 canals, 16 wells, 2 rain gauges and 1 weather station) record data every 15 minutes and are downloaded every 4 weeks, corresponding with a water quality sampling operation (Fig. 3). In addition, other agencies' data in the northern section of the Frog Pond (canal stages from SFWMD and well records from USGS) are being used to support the modeling effort.

Water Quality Sampling

Surface and groundwater quality samples are collected every two weeks at 21 different locations (5 canals, 16 wells) following QA/QC standard procedures (FL-DEP, 2002). Water quality samples are analyzed for concentration of 25 components including macro-elements (F, Cl, Br, SO_4-S, NH_4-N, NO_3-N, PO_4-P, total P, Ca, K, Mg, Na), trace elements (Cd, Co, Cr, Cu, Fe, Ni, Pb, Zn, Al, As, Mn, Mo, Se), pH and EC (see Appendix B).

In addition, atrazine concentrations for a subset of the samples (April-August, 2003) are being obtained through collaboration with the USGS Biological Resources Division (Ecotoxicology Program) in Gainesville.

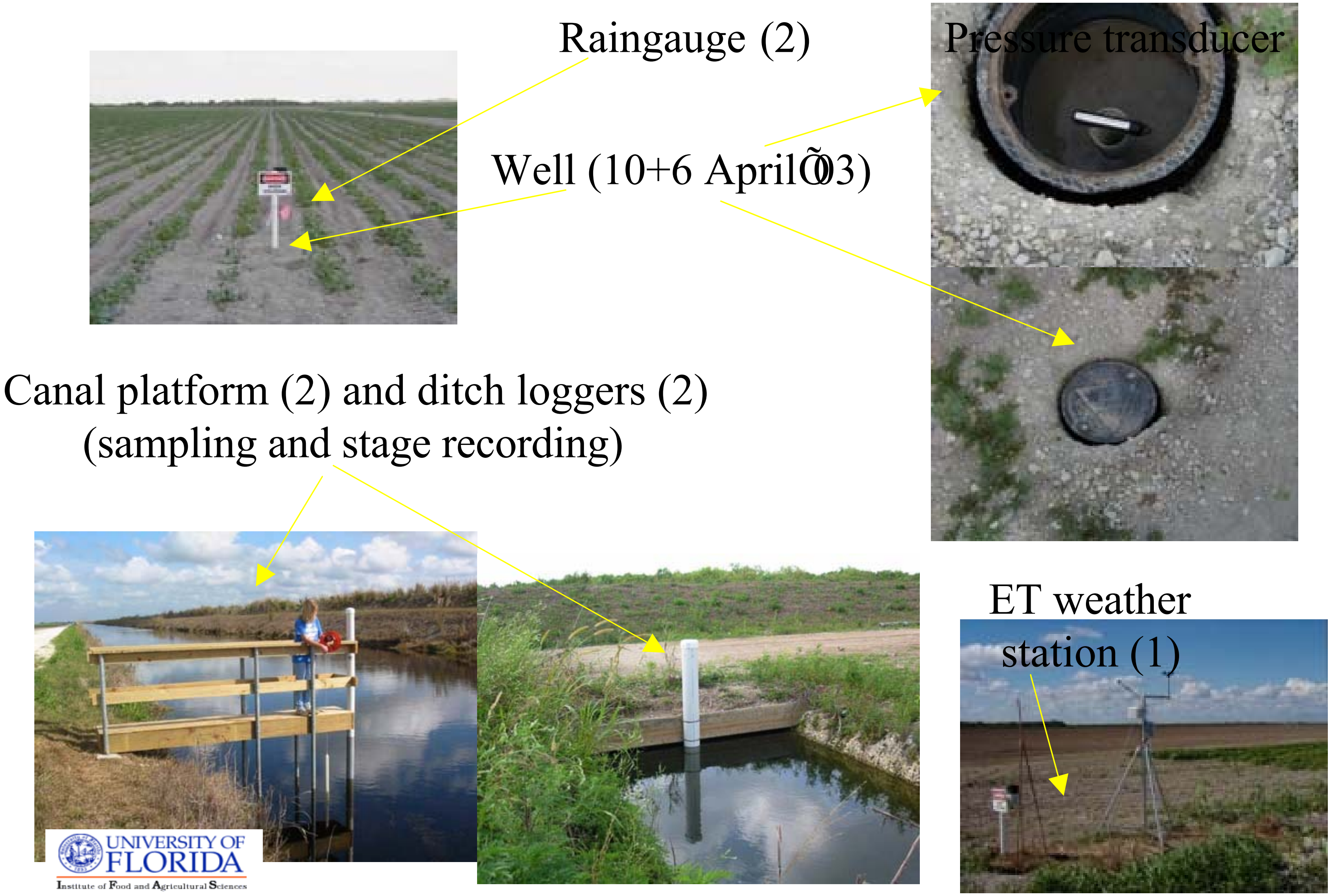

Figure 3. Details of field instrumentation

Data Maintenance, Exchange and Analysis: UF-HydroBase

To handle the extensive and complex hydrological and water quality dataset obtained in this project, an advanced online web-based information system for hydrological data storage, data maintenance and data mining, UF-HydroBase, has been developed (Muñoz-Carpena and Gonzalez, 2003). The main features of the system are:

- Based on industry standard Microsoft SQL server, ISAPI extensions and http protocol.
- IP clients on PC available to remotely upload and maintain data from Excel files.
- Advanced online graphing and reporting capabilities based on ActiveX objects.
- Allows working by project or comparing data across different projects.
- Flexible and able to handle a large number of projects and data sets.
- Excellent potential as a repository for other intensive hydrological projects.
- Designed to make Frog Pond hydrological data accessible to specialists and expert stakeholders.
- Data updated bi-weekly.
- Data types: groundwater elevations and depths (wells), surface water elevations (canals and ditches), rainfall (rain gauge networks), weather data, online daily ETP Penman-Monteith, soil moisture data, water quality data (macro-elements, tracers, organics, other) (Fig. 4-5).
- Automatic user selected units and Datum conversions (ft/m and NGVD29/NAVD88)

The system is accessible at http://carpena.ifas.ufl.edu. Login into to the system requires registration after which a password is issued.

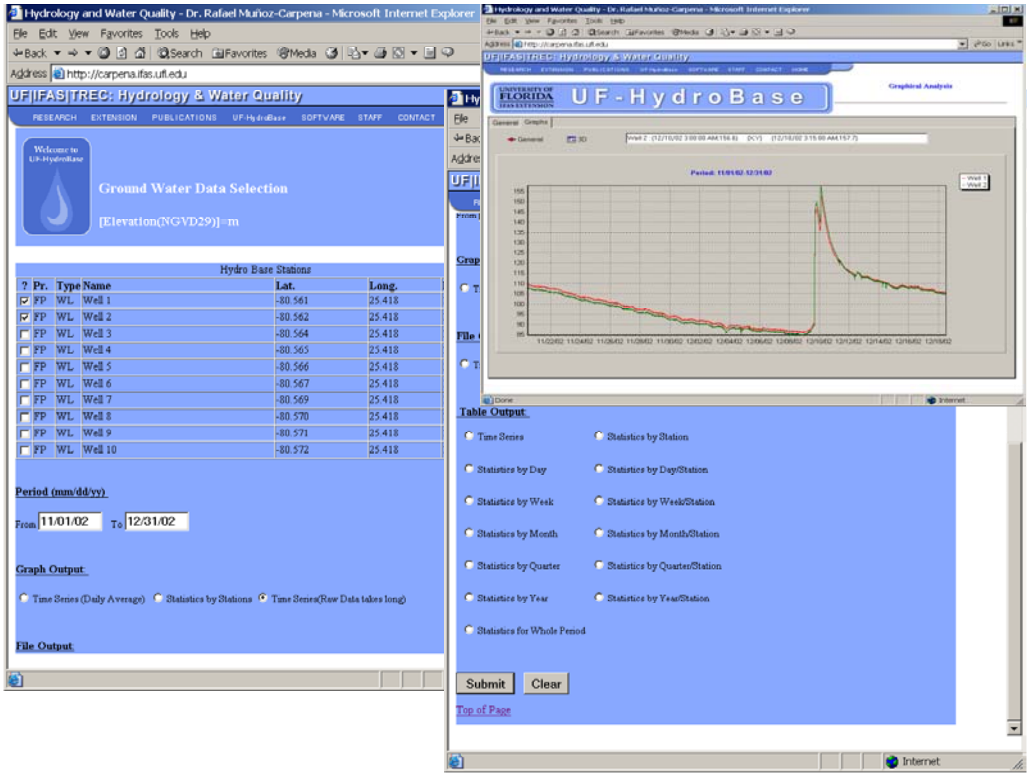

Figure 4. Groundwater data analysis in UF-HydroBase

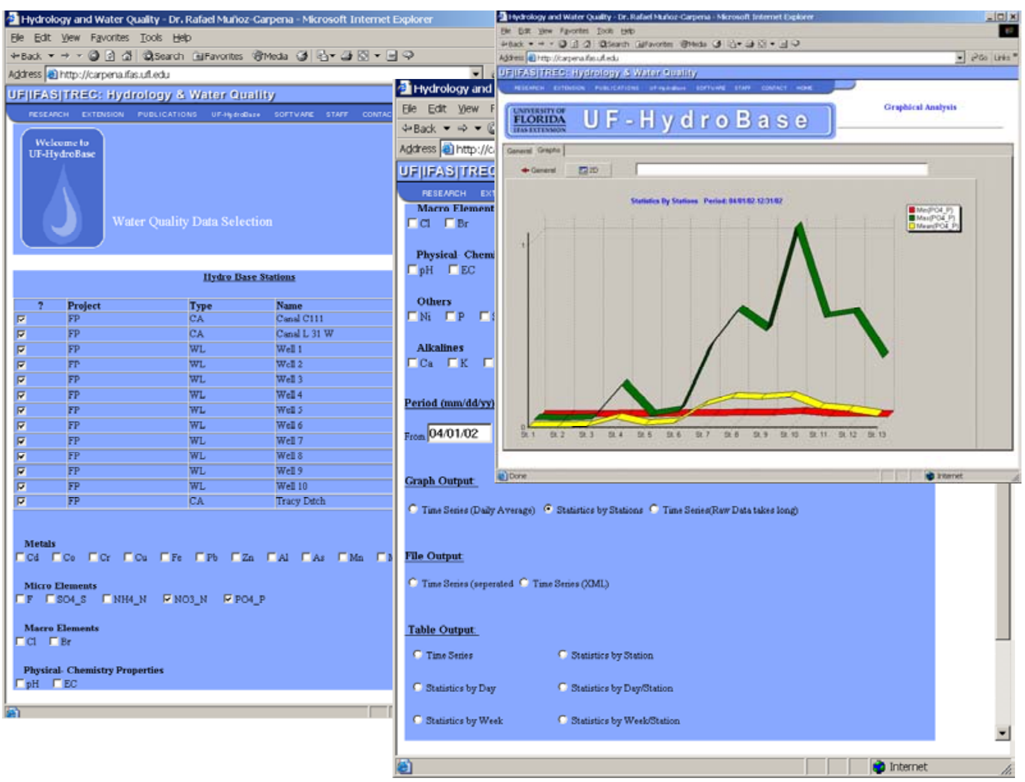

Figure 5. Water quality data analysis in UF-HydroBase

Computer Modeling

A three-dimensional groundwater-flow numerical model, MODFLOW (McDonald and Harbaugh, 1988), was selected as a tool to interpret the general groundwater flow in the area as well as to evaluate the impact of regional management strategies. The model, developed by the USGS, is based on a numerical (finite differences) solution to the saturated flow equations in a 2-D and 3-D domain. MODFLOW has been extensively tested around the world becoming a standard among academic, governmental and consulting professionals. The model is packaged under Visual Modflow (Waterloo Hydrogeologic, Inc.), an MS-Windows modeling environment that fully integrates the individual simulation capabilities of a number of groundwater models, including MODFLOW, with an inverse parameter optimization procedure (WinPEST) and facilities for 2D and 3D graphics visualization.

An initial steady state simulation was used as an exploratory tool to investigate the general groundwater flow trends in the area. Water levels of April 14, 2002 of SFWMD structures at canals L31-W and C111 were used as boundary conditions. System conditions during that time were free of rapid changes, so that quasi-steady state conditions could be assumed. Furthermore, the water elevation pattern on that date corresponded with the typical pattern of the recent water management procedures dictated by IOP (L31-W north of S175 > C111 north of S177 > L31-W south of S175). For this preliminary simulation the aquifer was assumed to be homogeneous and isotropic, with lateral saturated hydraulic conductivity K_s = 7590 m/d and a depth of 12 m, limited at the bottom by a semi-confining (Genereux and Guardiario, 1998). The simulation cells used were 79 x 79 m in size to ensure sufficient resolution.

The calibration and field-testing of the model in the Frog Pond area involved the following steps:

- First estimation of parameters from values derived from studies in the area (aquifer-drawdown analysis, tracer tests, other) and literature values.
- Optimization of the initial parameters through inverse modeling (WinPEST) using a subset of the experimental data (March-April, 2003).

- Field-testing of the model by comparing simulation results obtained with the optimized parameters with experimental values from an independent data set (March, 2002 through February, 2003).

Results

Hydrological Trends

a) Factors governing the hydrological system. General trends.

The temporal variation of three main hydrological components in the area (rainfall, surface and ground water elevations) is summarized in Fig. 6 for the one-year period (03/28/02-03/28/03).

Figure 6. Annual summary of hydrological components along the well transect

Although rainfall and canal management can potentially have the same impact on water table elevations (WTE), a visual inspection of Fig. 6 indicates that in general C-111 canal elevations control the trend in WTE, while rainfall is important when explaining sharp rises in WTE present in the dataset where there is no matching rise in canal elevation. These instances correspond to large storm events (i.e. June 3 and December 29, 2002).

The effect of the IOP interim management strategy on the L-31W stage level can be seen clearly on the lower part of Fig. 6, where the L-31W water elevation is 0.3-1.2 m (1-4 ft) consistently higher than in the C-111, with the exception of a period in February 2003. During this time the L-31W gate was opened to accommodate a canal-drawdown study carried out by the SFWMD.

The mean annual WTE for the period across the well transect is presented in Fig. 7. In general a smooth east to west down gradient is observed so that well 10, the nearest to the L-31W canal, has the lowest WTE.

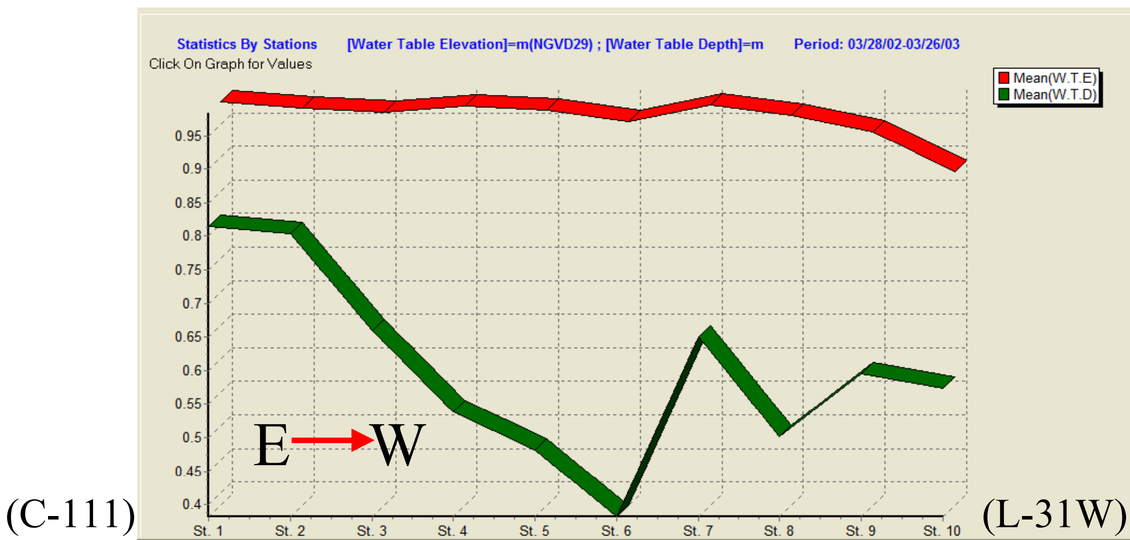

Figure 7. Mean annual water table elevation and depth along the well transect

This seems in contradiction with the nearby mean canal elevations where, as discussed before, the L-31W maintains the highest surface water elevation at all times. An explanation for this will be given in the modeling results below.

The water table depth (WTD, distance from the soil surface) is also included in Fig. 7. The dramatically varying WTD (compared to the smooth WTE profile) is due to the local changes in surface elevation around each one of the wells (around 30 cm or 1 ft). This illustrates the importance of micro-topography in the extremely flat lands of South Florida. This issue becomes more important the shallower the groundwater is. In our conditions, a 1 ft difference might compromise the value of the land for different uses (restoration, agriculture, landscaping, development, traffic, etc.). Currently there is no topographical data generally available in South Florida close to this resolution.

b) Seasonal water table variation.

To study the partial effect of precipitation and canal management on WTE in the area, the one-year experimental period was divided into 3-month periods (quarters, Q in Fig. 6). Mean quarterly water profiles (surface and ground) and total precipitation were obtained directly from UF-HydroBase and are presented in Fig. 8.

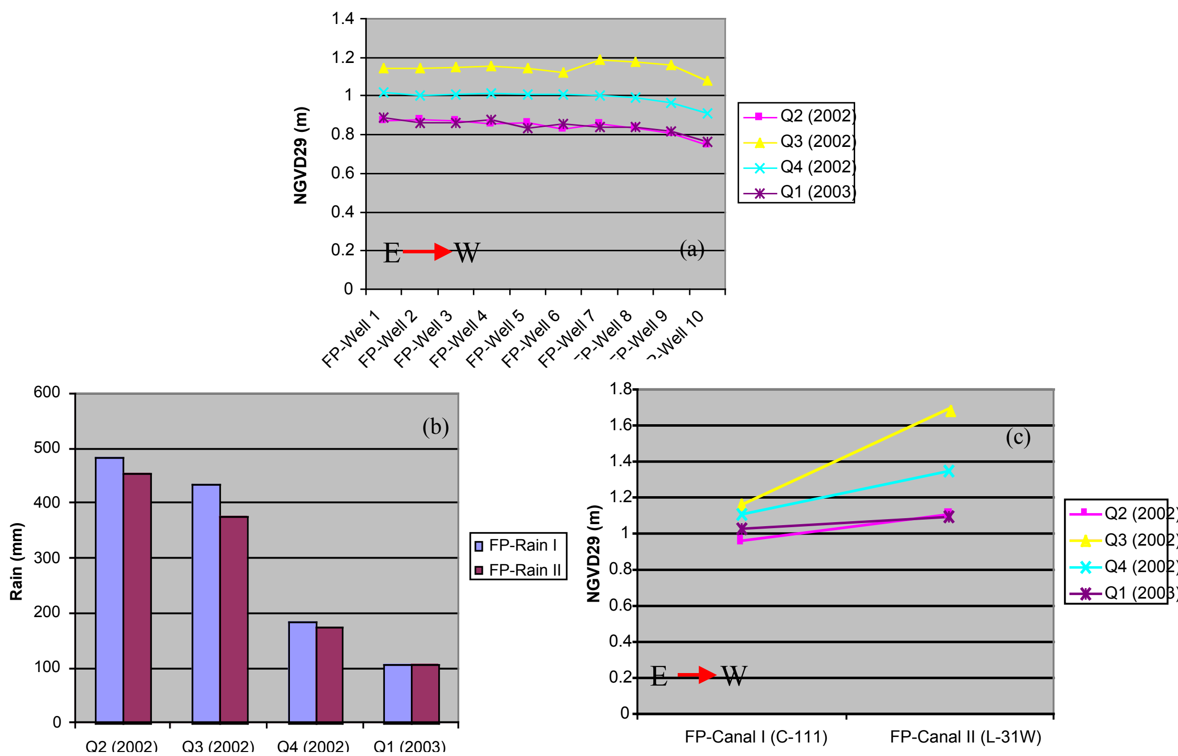

Figure 8. Analysis of main hydrological components affecting mean seasonal water table elevation

All mean quarterly WTE profiles are very similar in shape and slope, although a marked difference in elevation is found among them. The second 2002 and first 2003 quarterly [Q2(2002) and Q1(2003)] WTE profiles are almost identical to the lowest mean elevation, while Q3(2003) has the highest profile (Fig. 8a). Total quarterly precipitation is depicted in Fig. 8b. The two quarters with the same WTE have very different precipitations (the highest and the lowest of the four, respectively). This suggests that precipitation is not the driving factor to explain mean seasonal water profiles. Fig. 8c presents the mean quarterly canal water elevation for the period where Q2(2002) and Q1(2003) display almost identical values for the two canals. This confirms than in a managed system like the Frog Pond, the regional water management strategy (canal stages) is the main factor explaining the mean seasonal groundwater profile, rather than precipitation. However, as presented above, precipitation is important to explain instantaneous or localized groundwater responses that in some cases can be directly associated with the risk of flooding. The effect of precipitation is further studied in the next section.

c) Aquifer response to rainfall recharge: specific yield estimation.

The high-resolution time scale (15-minute readings) of the water levels (ground and surface) dataset allows for an analysis of aquifer response to rainfall recharge. If net flow (lateral and vertical) at the observed point is assumed as zero and there is no delay due to infiltration through the topsoil, the aquifer recharge can be set equal to rainfall input. These conditions can be met during relatively large and short rainfall events on extremely permeable materials like the ones present in the area. Under these conditions an upper boundary value for the specific yield, S_y, can be simply defined as

$$S_y = \frac{\text{Recharge}}{\text{Head difference}}$$

S_y is an important aquifer parameter that quantifies the local aquifer changes (drawdown or rise) when pumping or recharge occurs.

The proposed simplifying assumptions held during Dec 9-10, 2002 (Figs. 6 and 9), when a sharp rise in the groundwater was registered in all transect wells in response to two consecutive, large rainfall events. The first and largest event (71 mm or 2.8 in) took place from 15:49-17:20 on Dec 9, followed by a smaller one (23 mm or 0.9 in) from 1:30-3:10 am. An almost instantaneous groundwater elevation was observed along the well transect (Fig. 9) during the event. Under these conditions the simple estimation of S_y for the first event led to very consistent results for the five inner wells (3 – 7) of the well transect, with a value of S_y = 0.115. This value closely matches the value obtained in the area by Bolster et al. (2001) from a complex canal-drawdown experiment.

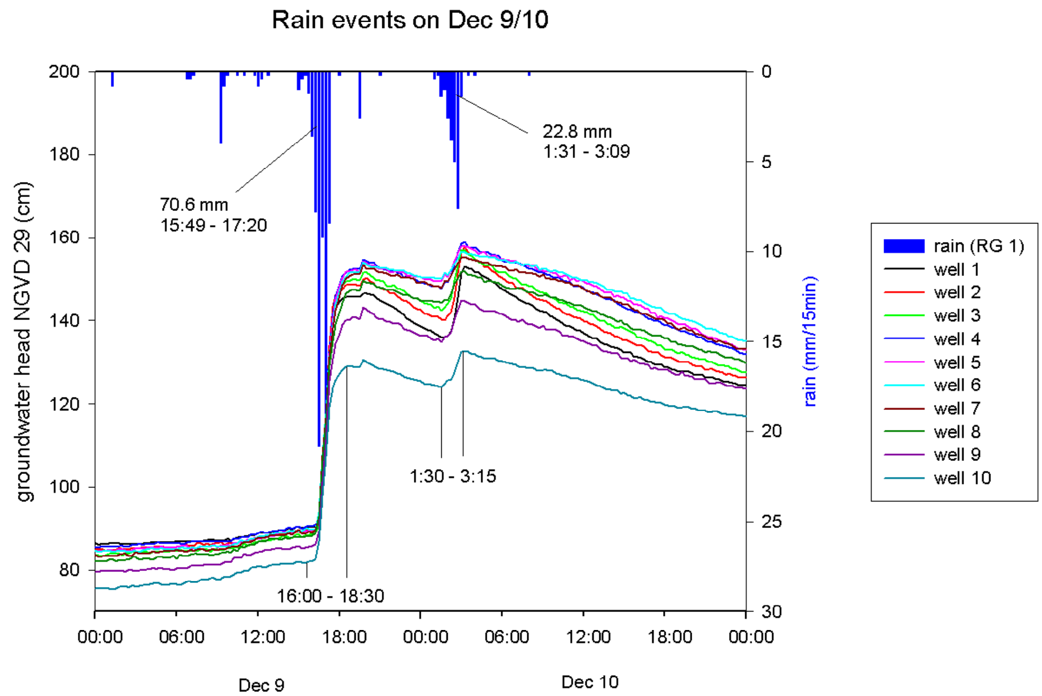

Figure 9. High-resolution temporal analysis for event on Dec. 9, 2003

This indicates that for the upper layer of the shallow aquifer (top 60 cm or 2 ft. below ground surface) a ratio of recharge to water table rise of 1:8.7 could be expected for large storms of short duration. For example, if the water table is within 2 feet of the surface and the net flow at the point is zero, 1 in of rainfall will result in a water table raise of about 8.8 in. This value is in apparent contradiction with the general value accepted for the area, 1:3 (1 in rainfall=3 in water table raise). A possible explanation is that the latter is derived as the average yield for the top 3 m (10 ft) of the ground corresponding to the general range of water table fluctuation in the area. The much lower yield found close to the surface (top 60 cm, 2 ft) in our study corroborates the marked vertical heterogeneity existing in the Biscayne Aquifer presented by Genereux and Guardiario (2001). It might also be caused by the filling of secondary solution pore spaces with fine material, mobilized with the "rock-plowing" of the thin overlaying soil layer. Another practical application of this finding is the fact that when the water table is already close to the surface, the risk of flooding can actually be up to three times greater with respect to the risk calculated with the general value of 3 in.

d) Annual water fluctuation and flooding

Complete flooding (water standing on soil surface) was experienced in 40% of the wells in the transect, with as much as 0.23 m (9 in) of ponding in well 6 in one instance after the event on Dec 9, 2002. All the wells had water within 0.15 m (6 in) of the surface at least one time during the period. This top 15 cm usually corresponds to the “rock-plowed” soil layer.

The maximum water table depths (from the surface) along the transect ranged from 0.91-1.35 m (3.0-4.4 ft) and were registered the first week in March 2003. Seasonally, the highest mean water elevation corresponded to the third quarter of years 2002 and 2003 while the lowest was recorded during the first quarter of both years.

Modeling Results

a) Surface-ground water interaction along the experimental transect.

Results from an initial steady state exploratory simulation are depicted in Fig. 10, where the continuous lines indicate piezometric surfaces and the arrows show flow direction and velocity (length of the arrow).

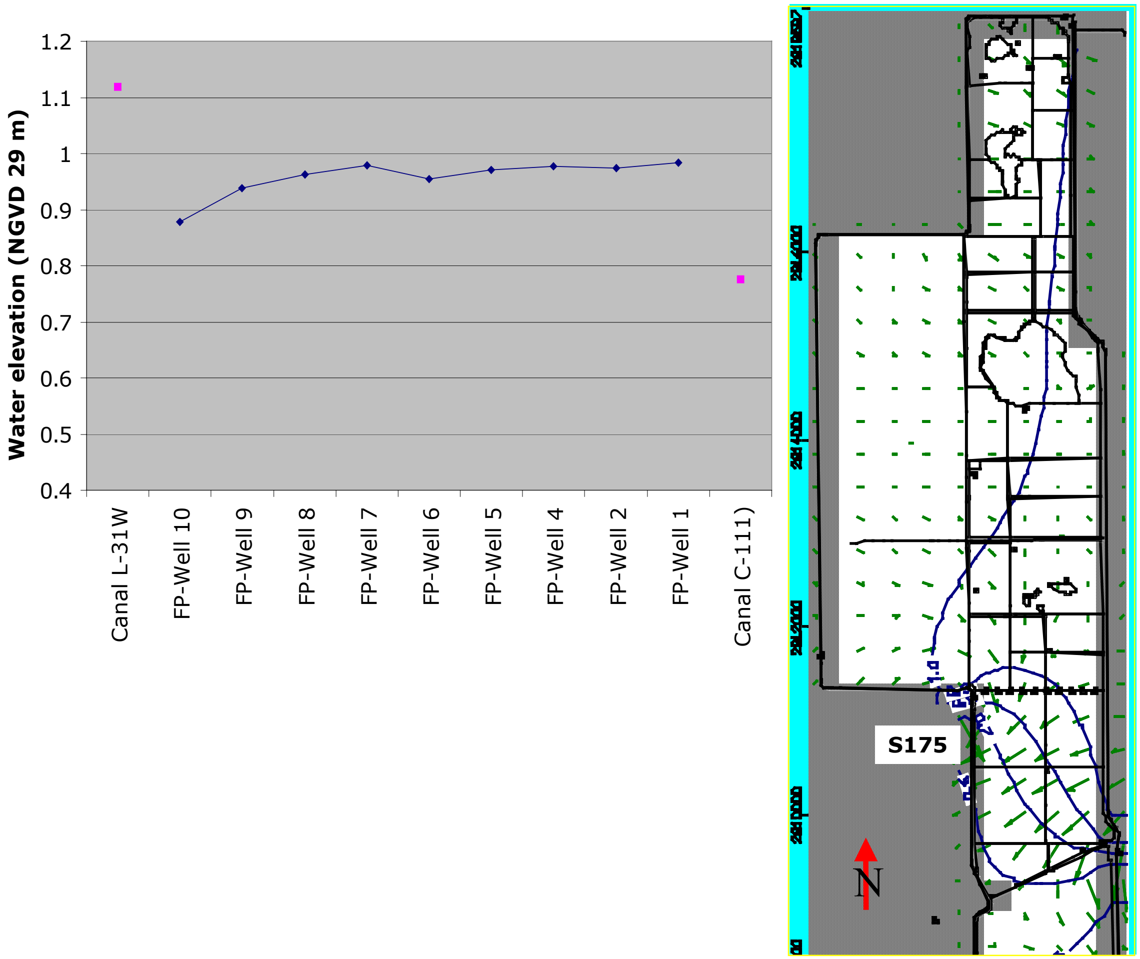

Figure 10. Steady state groundwater flow modeling to explain anomalous correlation between mean groundwater and canal levels

The results show the profound effect that the permanently closed gate at structure S-175 (associated with IOP) has on the general groundwater flow in the southern portion of the Frog Pond. The sharp gradient of around 1 m (3 ft) between head and tail waters of the structure shifts the general west to east groundwater flow, turning it around the structure with increasing speed and eventually west towards the ENP on the south of the structure. Based on the simulation, the flow perturbation reaches around 1.6-3.2 km (1-2 mi) around the structure. These simulation results explain the apparent contradictory relationship observed at the well transect between canal and groundwater elevations (see insert in Fig. 10). The field results showed that the groundwater elevation along the well transect generally decreased from east to west, while on the other hand the canal elevation was higher in the west (north of S-

175 in L-31W) that in the east (C-111). A visual comparison between the simulation and the mean annual water profile along the well transect justifies the experimental values.

b) Groundwater model calibration and study of the effect of the detention pond operation.

Initial work has been in progress to establish a calibrated version of Visual MODFLOW for modeling hydrological flow in the Frog Pond (Morawietz and Muñoz-Carpena, 2003). Inverse calibration has been performed, using data from UF-HydroBase and DBHYDRO (SFWMD) as boundary conditions, to determine values for a number of system parameters selected for calibration. Further validation of these calibrated values was then carried out using sets of observed data for comparison, and these simulated results provide important insight into hydrological flow patterns within the Frog Pond. Of particular interest are the influences of canal and detention pond stage on the groundwater dynamics, which allow initial evaluations to be made on effectiveness of the detention pond.

Data from the quasi-steady state conditions observed on June 13, 2003 was used for the calibration on Figures 11(a) and (b), which show the simulation results for the Frog Pond under two conditions:

1. with 300,000 m^3/day pumped into the detention pond maintained at the observed depths of 2.4 and 1.8 m NGVD29, in cells 1 and 2, respectively (Figure 11a);
2. with pump off and the detention pond empty (L-31W level as boundary condition, 1.61 m NGVD29) (Figure 11b).

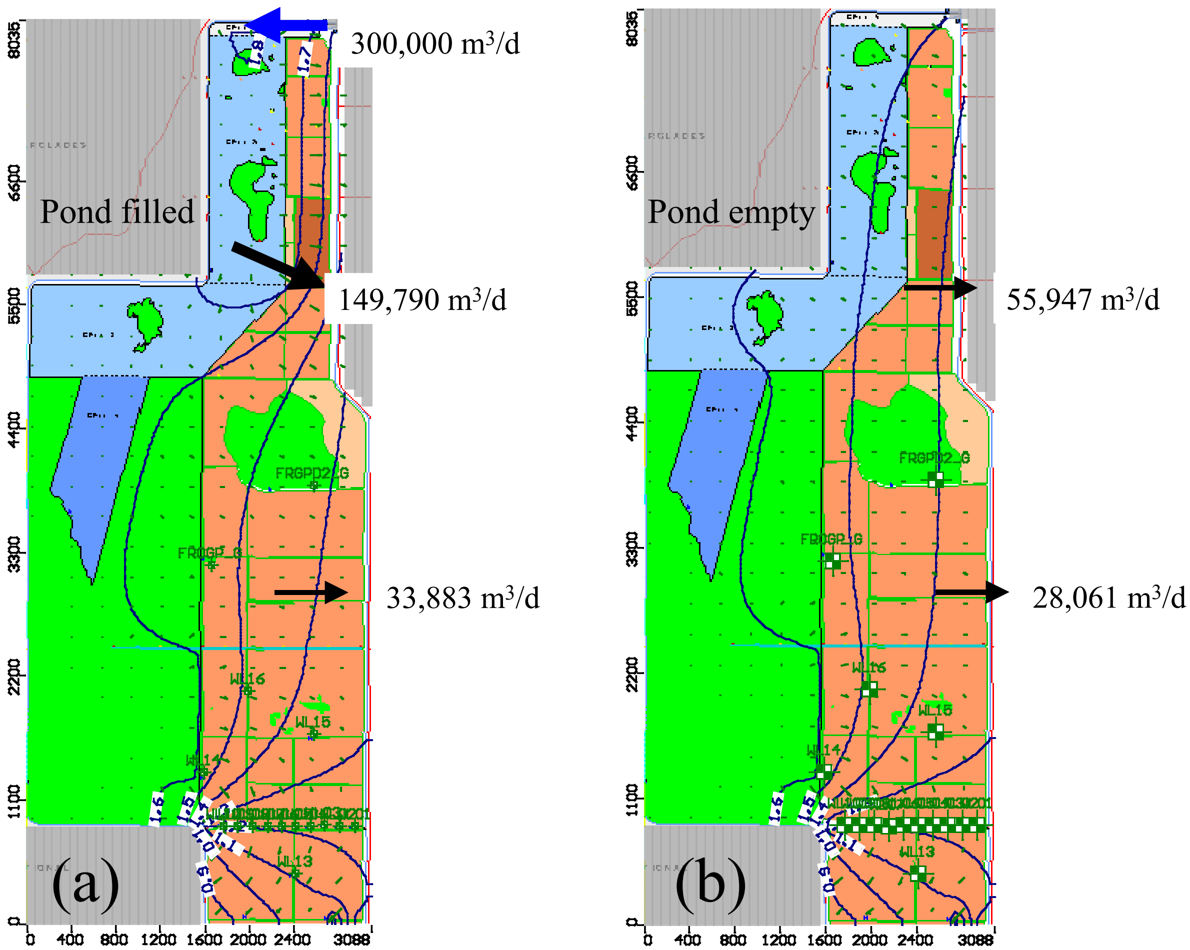

Figure 11. Frog Pond Visual MODFLOW simulation results with (left) detention pond filled and (right) detention pond empty (after Morawietz and Muñoz-Carpena, 2003)

In the first scenario (detention pond filled), there are major water losses in the direction of the eastern canal C111. These are due to low water level in the canal, leading to a high gradient between cell 2 and the canal, and to unsealed cell beds that result in little resistance to infiltration (large seepage).

In the second scenario the overall seepage is reduced to half (94,000 vs 180,000 m^3/d). Although seepage to the southern part of the C-111 stays the same, seepage to the northern section is reduced 3-fold (150,000 to 56,000 m^3/d).

In summary, the detention pond is filled in Cell 1 and 2 over 30% of water pumped into the detention pond for that event is lost back to the groundwater system through seepage. This clearly raises questions about the effectiveness of the detention pond in performing any of the three primary functions outlined previously (wetland breeding habitat maintenance, surface water storage and surface water cleaning before release to ENP).

The results in Figure 11 confirm the initial evaluation of the canal gate operation at the S-175 structure in canal L-31W as part of the new management strategy. The permanent closure causes significant perturbation effects on flow patterns near the structure. Flow is pulled south and ultimately westwards back towards L-31W, a characteristic that dominates the hydrological processes in the south of the Frog Pond irrespective of the state within the detention pond.

With regard to the validity of the simulation results obtained, an absolute residual mean of 2.1 cm and a normalized root mean square error of 6.3 % were found, and are considered satisfactory for such a simulation. Figure 12 below is a graphical presentation of the correlation between simulated and observed heads throughout the Frog Pond area, and illustrates the reliability of the results.

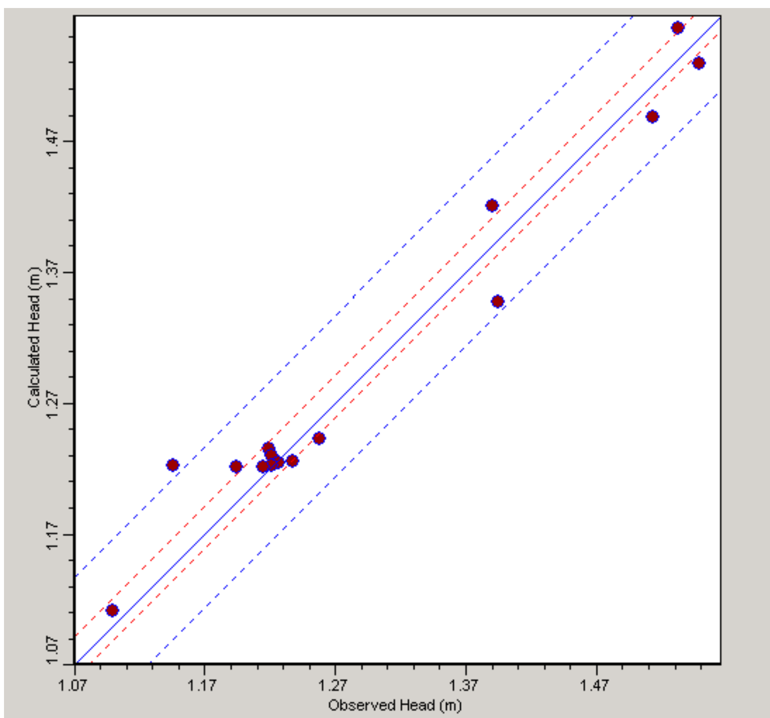

Figure 12. Correlation of observed head and simulated head by Visual MODFLOW for the Frog Pond (Morawietz and Muñoz-Carpena, 2003)

Water Quality Trends

a) Macro-elements

a-1 Phosphorous

The mean and maximum concentrations of total P and Ortho-P in water samples collected bi-weekly from surface waters (C-111 and L-31W canals, Torcise ditch) and monitoring wells in the transect (10 in total) in the Frog Pond were:

Table 1. Frog Pond phosphorous level in surface and groundwater during 03/28/02-03/26/03

	Ortho-P (ppb μg/L)		Total P (ppb μg/L)	
Sampling Location	Mean	Maximum	Mean	Maximum
C-111	4	17	26	54
L-31W	8	74	30	69
Ditch	7	31	36	58
Wells (1-10)	13-134	1068	55-181	1174

Concentrations of total P in surface waters exceeded 10 ppb in 90% of the samples (21 of 24 samples for C-111 canal and 22 of 24 samples for L-31W) (Fig. 13). Concentrations of total P from canal L-31W were consistently higher than those obtained from C-111 canal.

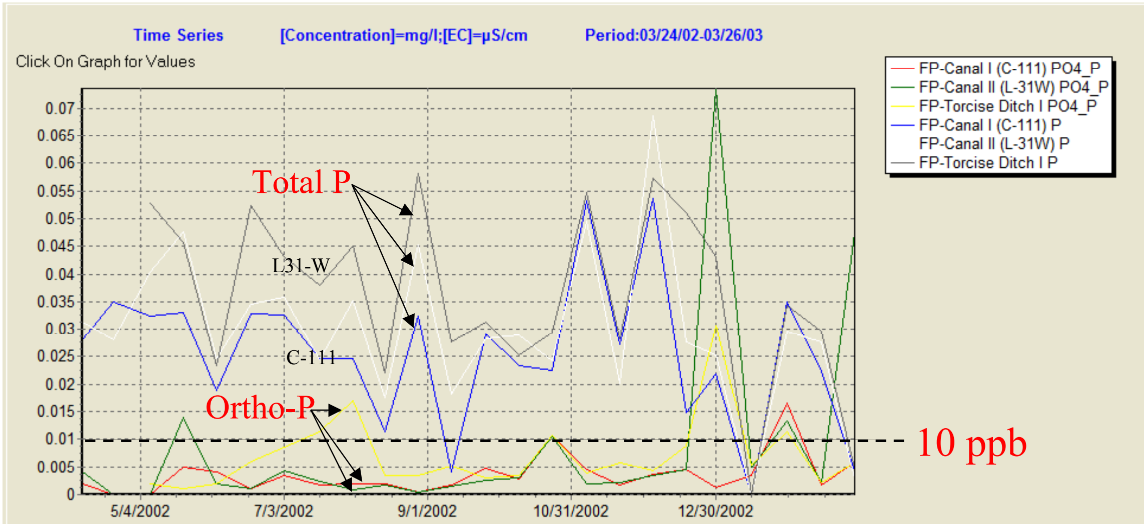

Figure 13. Annual phosphorous concentrations in surface waters

Concentrations of total P and Ortho-P in water samples from the monitoring wells were high during May-August (summer rainy season), and August-December (early growing season of vegetable crops) (Fig. 14).

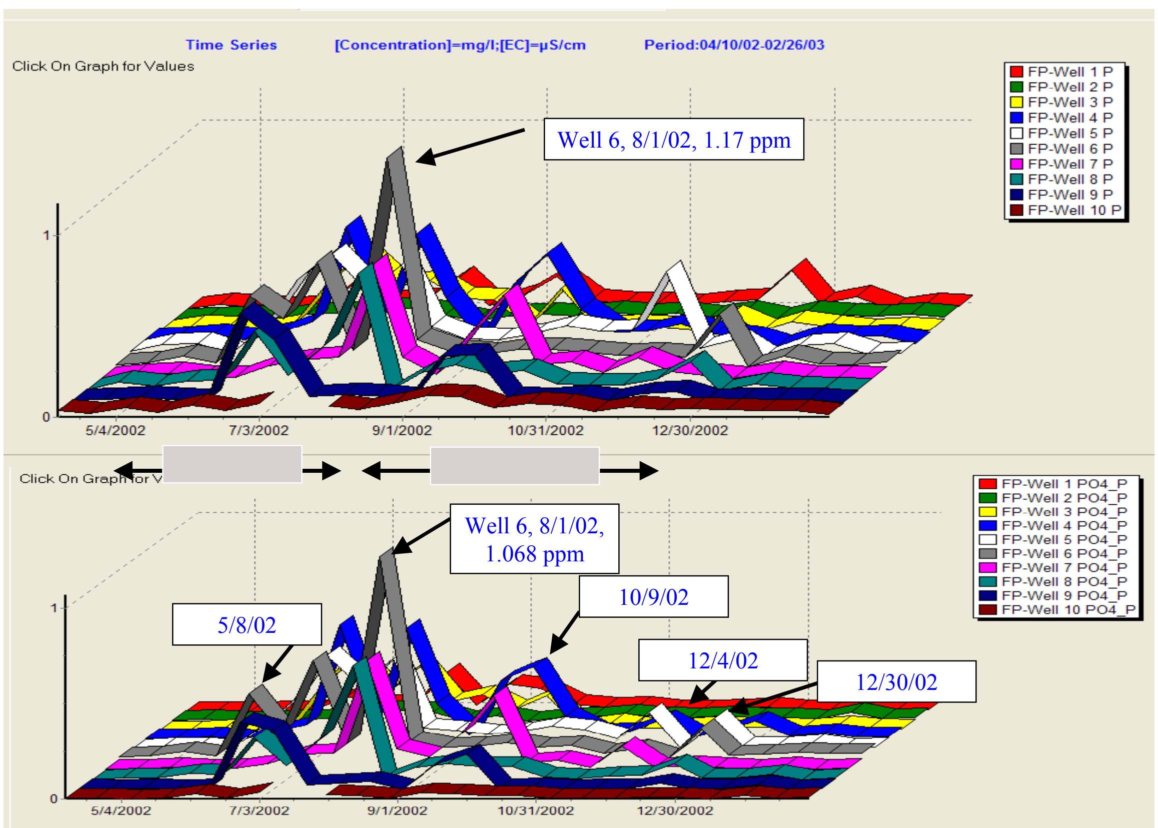

Figure 14. Annual phosphorous concentrations in groundwater samples

a-2 Nitrogen

Concentrations of nitrate-nitrogen in all surface and groundwater samples were below 10 ppm (U.S. drinking water standard) except for one sample collected in well 2 (June 5, 2002) and another in well 3 (June 19, 2002).

On a monthly basis, the higher groundwater nitrate concentrations were observed during the rainy season (May-August), with a second (lower) increase at the beginning of the winter crop season (September-November) (Fig. 15). There is a high correlation (R^2=0.61) between the mean monthly groundwater concentration of nitrate and rainfall in the samples, indicating a rapid mobilization (leaching) from the enriched topsoil when the rain falls. The second peak at the beginning of the crop season can also be attributed to the fertilizer applied to the soil (in beds or pre-planting).

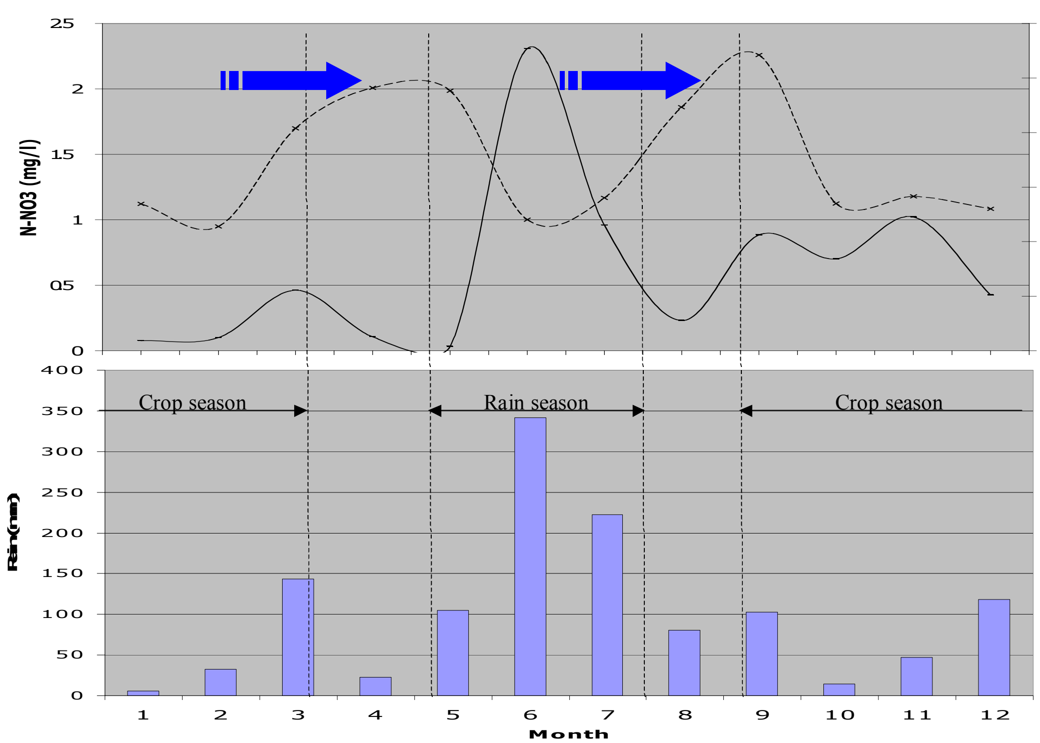

Figure 15. Annual nitrogen concentrations in ground water samples (the big arrows on top denote chemical reduction of nitrate to ammonia in the groundwater)

Ammonia in groundwater follows an inverse pattern to nitrate, i.e. the ammonia mean monthly values are higher when the nitrate is low (Fig. 15). This might be largely the result of the chemical reduction of the nitrate that was leached previously to ammonia (see big arrows in Fig. 15).

Monthly nitrate and ammonia surface water concentrations followed a similar pattern to the one described for groundwater (i.e. inverse ammonia and nitrate patterns) but shifted (delayed) in time around 1.5 months (peak in August rather than in June). However, although the ammonia concentrations in both ground and surface waters were similar (means of 0.17 and 0.10 mg/l, respectively), surface nitrate concentrations were much lower, by around one order of magnitude (means of 0.5860 and 0.0592 mg/l, respectively), with a range similar to that of ammonia.

a-3 Sulfate and Bromide

Sulfate is a common component of inorganic fertilizers while methyl bromide was used in the area in the past as a soil fumigant. Although generally low concentrations were obtained, several spikes of SO_4-S and Br- were detected in water samples during the vegetable season. Mean well values were higher than mean canal values what indicates that the origin might be internal to the Frog Pond.

a-4 Other

Concentrations of other macro-elements analyzed (F, Cl, Ca, K, Mg, Na) were low and within natural and regulatory levels.

b) Trace Metals

b-1 Copper

Copper is widely used as a fungicide for crop production. A high concentration of Cu was found in water samples from canals, ditch and wells in September 2002. Concentrations were generally higher in groundwater samples than in canal ones, suggesting an internal origin or possibly applications in the agricultural area east and north of the Frog Pond (Fig. 16).

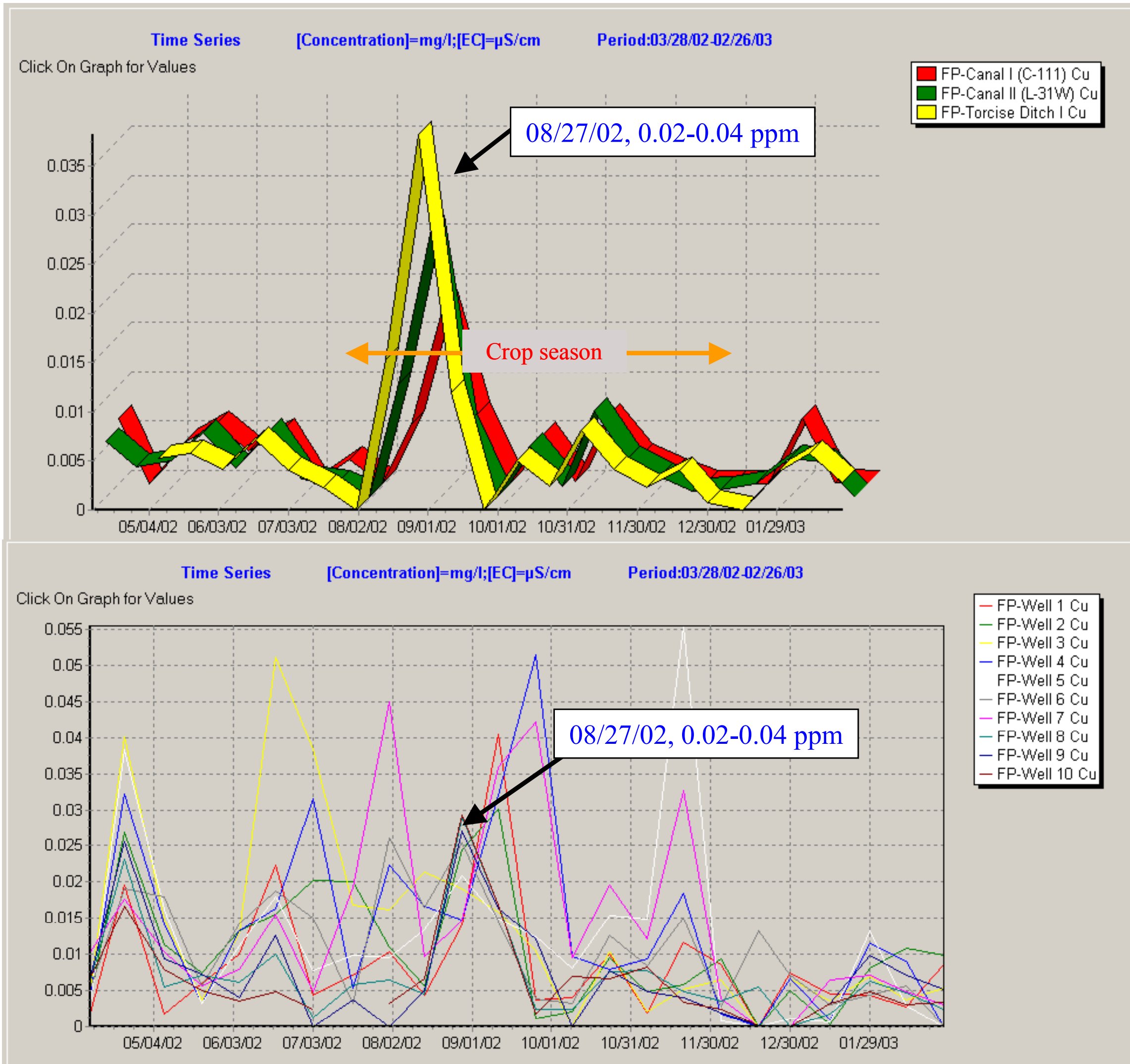

Figure 16. Annual copper concentrations in surface and groundwater samples

b-2 Other

Concentrations of trace metals in most of water samples were below detection limits or very low. However, some water samples showed relatively high concentrations of arsenic (69 ppb in Torcise ditch), Cd (23 ppb in Torcise ditch), Co (31 ppb in Well 1), Cr (31 ppb in Well1), Ni (34 ppb in Torcise ditch), Pb (128 ppb in well2), and Se (98 ppb in Torcise ditch). Although some of these elements are naturally present in the aquifer material, a detailed mass balance coupled with flow is needed to determine the origin and concentration paths.

Extension Activities

The results and information from this project are being made available through the University of Florida IFAS-Extension programs. A public seminar for growers was organized at the Miami-Dade Extension Office in 2002, where speakers from the agencies involved in the C-111 Project (SWFMD, ENP, Corp of Engineers, University of Florida) were invited to present an overview of the conditions in the area and an outline of the project was given. The status of the research was presented at two agency meetings in 2003 (SFWMD in Homestead and USDA-ARS in Miami). Several presentations sponsored by the SDSWCD were given both for growers in the area as well as the Board members. Other presentations were given in 2003 to the SFWMD director (in Homestead) and the SFWMD Storm Water division technical staff (in West Palm Beach). A project summary has been published online through the TREC's Hydrology web site (http://carpena.ifas.ufl.edu). Several extension documents are in preparation and will be released later in 2003. A stakeholder's workshop about the results from this project is planned for September 1, 2003 at the Miami-Dade Extension Office. A training session for the online system (UF-HydroBase) will be given this year for board members of the SDSWCD and other interested parties.

A new proposal for continuation of work in the area has been submitted to the SFWMD. This proposal includes a significant educational component including the development of advanced educational material (computer animation, documentary). The monitoring network (field and online components) has the potential to become a demonstration project to be used in a number of future watershed training programs through the University of Florida.

Future Research and Education Needs

A sufficiently long record of data that includes inter-annual variability is essential to fully accomplish some of the tasks initiated herein. A continuation of the present study for an additional two and a half years (to a total of 4 years) should provide the basis for an in depth study of some of the particular hydrological mechanisms that affect flow and chemical transport in the area (dual flow and matrix effects, chemical transformations particular to the limestone materials, etc.).

Continued monitoring with the concurrent operation of the newly constructed C-111 Project detention area during the next two years will provide an invaluable opportunity to assess the effect of these new areas. This will also lead to further refinement and testing of the selected (and other) computer models to become a powerful tool for evaluation of alternative operation plans, and to assess the effectiveness of BMP's to mitigate potential impacts in surrounding areas.

The expanded database will also open the opportunity for a quantitative assessment of the chemical balance and transport in the area by combining the improved understanding of flow patterns, water quality trends and chemical transport models. To date, all modeling progress has been purely hydrological in nature. Water quality investigations have thus far been qualitative and based predominantly on the analysis of data collated in UF-HydroBase. No qualitative evaluations have been made incorporating the flow pattern results from hydrological simulations, and as yet no there has been no advancement in plans for further calibration of Visual MODFLOW to incorporate contaminant transport and hence facilitate quantitative analysis of water quality in the area. These are clearly important issues that require further attention.

Results from the model calibration and comparison for two scenarios (one with detention pond filled and one not filled) are being processed and will be the subject of a publication presented at the International Meeting of the American Society of Agricultural Engineers (ASAE) in July 28-31, 2003.

In addition, the existing monitoring network (field and online components) has the potential to become an outstanding educational tool, both as a demonstration project and as a platform to produce sophisticated educational materials. The expanded data set, when combined in the form of a computer animation (like a cartoon) can help to illustrate, in a very graphical and understandable manner, how fast the groundwater responds to the canal operation (in some cases within minutes even a mile away from the canal) or to rainfall events of different magnitude.

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- Frank J. González, Computer Engineer (UF-TREC Homestead)
- Karen Minkowski, GIS Specialist (UF-TREC Homestead)
- Mike Gutierrez, Biologist Technician (UF-TREC Homestead)
- Diego Funes, undergraduate summer student intern (UF Gainesville)
- Brian Rafie, high school summer student intern (Homestead High School)
- Tomas Marino, Technician (UF-TREC Homestead)
- Stuart Muller, Graduate Student (UF ABE Dept. Gainesville)
- Guiquin Yu, Laboratory technician (UF-TREC Homestead)
- Laura Rosado, Laboratory technician (UF-TREC Homestead)

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APPENDICES

A - Table of Existing Monitoring Stations

Project	Station	UTM NAD 83 Zone 17				Elev. NAD 88 (ft)				Elev. NGVD 1929 (ft)				Elev. NAD 88 (m)				Elev. NGVD 1929 (m)			
	Well ID	Easting	Northing	Lat.	Long	North Rim	Well Elev.	Dist. Surf.	Ground Elev	North Rim	Well Elev.	Dist. Surf.	Ground Elev	North Rim	Well Elev.	Dist. Surf.	Ground Elev	North Rim	Well Elev.	Dist. Surf.	Ground Elev
FP	WL01	544164	2811339	25.418314	80.5608	4.18	3.55	0.79	4.34	5.74	5.11	0.79	5.90	1.273	1.082	0.240	1.322	1.749	1.558	0.240	1.798
FP	WL02	544029	2811339	25.418314	80.5622	4.11	3.73	0.54	4.27	5.68	5.29	0.54	5.83	1.254	1.138	0.165	1.303	1.730	1.613	0.165	1.778
FP	WL03	543896	2811346	25.418367	80.5635	3.04	2.76	1.02	3.78	4.60	4.32	1.02	5.34	0.926	0.841	0.312	1.153	1.402	1.316	0.312	1.628
FP	WL04	543771	2811339	25.418307	80.5648	2.72	2.14	1.27	3.41	4.28	3.70	1.27	4.97	0.830	0.652	0.387	1.039	1.305	1.128	0.387	1.515
FP	WL05	543642	2811340	25.418320	80.5660	2.77	2.01	1.19	3.20	4.33	3.57	1.19	4.76	0.845	0.612	0.364	0.976	1.321	1.088	0.364	1.452
FP	WL06	543510	2811341	25.418333	80.5673	2.67	1.98	0.84	2.82	4.23	3.54	0.84	4.38	0.814	0.604	0.257	0.861	1.290	1.079	0.257	1.336
FP	WL07	543387	2811338	25.418305	80.5686	3.03	2.47	1.31	3.79	4.59	4.03	1.31	5.35	0.923	0.754	0.400	1.154	1.399	1.230	0.400	1.630
FP	WL08	543252	2811342	25.418342	80.5699	3.13	2.28	0.96	3.24	4.69	3.84	0.96	4.80	0.954	0.694	0.294	0.988	1.430	1.170	0.294	1.464
FP	WL09	543121	2811343	25.418351	80.5712	2.77	2.32	1.15	3.47	4.33	3.88	1.15	5.03	0.843	0.707	0.351	1.058	1.319	1.183	0.351	1.534
FP	WL10	542993	2811342	25.418342	80.5725	2.18	1.79	1.41	3.20	3.74	3.35	1.17	4.53	0.665	0.547	0.357	0.904	1.141	1.022	0.357	1.379
FP	WL11	543961	2810529	25.411000	80.5629	N/A	7.70	-3.01	4.69	N/A	9.26	-3.01	6.26	N/A	2.347	-0.916	1.431	N/A	2.823	-0.916	1.907
FP	WL12	543237	2810539	25.411100	80.5701	N/A	6.27	-2.66	3.61	N/A	7.83	-2.66	5.17	N/A	1.911	-0.810	1.101	N/A	2.387	-0.810	1.577
FP	WL13	543636	2810918	25.414500	80.5661	4.45	4.13	0.31	4.44	6.01	5.69	0.31	6.00	1.356	1.259	0.094	1.353	1.832	1.735	0.094	1.829
FP	WL14	542822	2811812	25.422600	80.5742	3.17	2.86	0.73	3.59	4.74	4.42	0.73	5.15	0.967	0.871	0.223	1.094	1.443	1.347	0.223	1.570
FP	WL15	543801	2812159	25.425700	80.5644	2.91	2.70	0.61	3.30	4.47	4.26	0.61	4.86	0.888	0.822	0.185	1.007	1.364	1.298	0.185	1.483
FP	WL16	543216	2812543	25.429200	80.5702	3.12	2.75	0.67	3.42	4.68	4.31	0.67	4.99	0.951	0.839	0.205	1.044	1.427	1.314	0.205	1.519

						Elev. NAD 88 (ft)	Elev. NGVD 1929 (ft)	Elev. NAD 88 (m)	Elev. NGVD 1929 (m)
	Canal loggers	Easting	Northing	Lat.	Long	Pipe Elev	Pipe Elev	Pipe Elev	Pipe Elev
FP	CA01	544291	2811335	25.418278	80.5596	9.00	10.56	2.743	3.219
FP	CA02	542868	2811317	25.418116	80.5737	12.10	13.66	3.688	4.164
FP	CA03					----	----	----	----
FP	CA04	542824	2812943	25.432819	80.5741	6.47	8.03	1.971	2.447
FP	CA05	542033	2812937	25.432763	80.5820	7.26	8.83	2.214	2.690

B- Water sampling, Preparation and Analysis

The water samples were collected into cleaned and labeled 500 ml bottles. The date of sampling was noted on the labels. The samples were stored in an ice-chest with ice and transported to the Soil and Water laboratory, TREC, University of Florida. The water samples were prepared immediately on receipt and transferred in refrigeration before analysis. The determination of various parameters in the samples is given as follows:

1. Water pH was determined using a pH meter (Orion 501, Orion Research Incorporated, Boston, MA) and EC were measured using a conductivity meter (Accumet Model 30, Denver Instrument Company, Arvada, CO)

2. Total P, ortho-P and NH_4 and NO_3 were analyzed using an Autoanalyzer (AA3, Bran+Luebbe, Buffalo Grove, IL)

3. Anions (F, Cl, Br, and SO_4-S) were analyzed using an Ion Chromatography (Dionex 500, Dionex Corporation, Sunnyvale, CA)A

4. Metals (Ca, K, Mg, Na, Al, Cd, Co, Cr, Cu, Fe, Ni, Pb, Zn, As, Mn, Mo and Se) were analyzed using an ICPAES (Inductively-Coupled Plasma Atomic Emission Spectrometer) (Ultima, JY Horiba Group, Madison, NJ).